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Smoke Features Simulation of Vehicle Fires in Large Cross-Section Road Tunnel

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ABSTRACT: Based on CFD simulation method, the smoke distribution features of vehicle fires in large cross-section road tunnel were discussed in this paper. As for different kinds of longitudinal ventilation velocity, the simulation results for spreading velocity and scope of the smoke in the tunnel fire were analyzed.

1 INTRODUCTION

In recent years, with the rapid development of the road construction, more and more tunnels appear. The fire accidents in the road tunnels may cause tremendous damage and disaster, especially the hurt of the fire smoke. Thus some useful measures should be taken to control the tunnel fire. Longitudinal ventilation system is always adopted to control the spreading scope of fire smoke in a road tunnel fire emergency. According to the ventilation system of road tunnel as well as the theory of CFD (Computational Fluid Dynamics), the smoke development results of tunnel fire in different situations could be simulated using computer numerical method. As for different kinds of longitudinal ventilation velocity, this paper constructed a fire simulation model for large cross-section road tunnel and carried out four simulations for vehicle fires with the CFD software of FDS (Fire Dynamic Simulator). The efficient ventilation control measures for vehicle fires in road tunnel were also suggested.

2 DESIGN OF FIRE SCENARIO FOR CFD

2.1 Brief Introduction of FDS

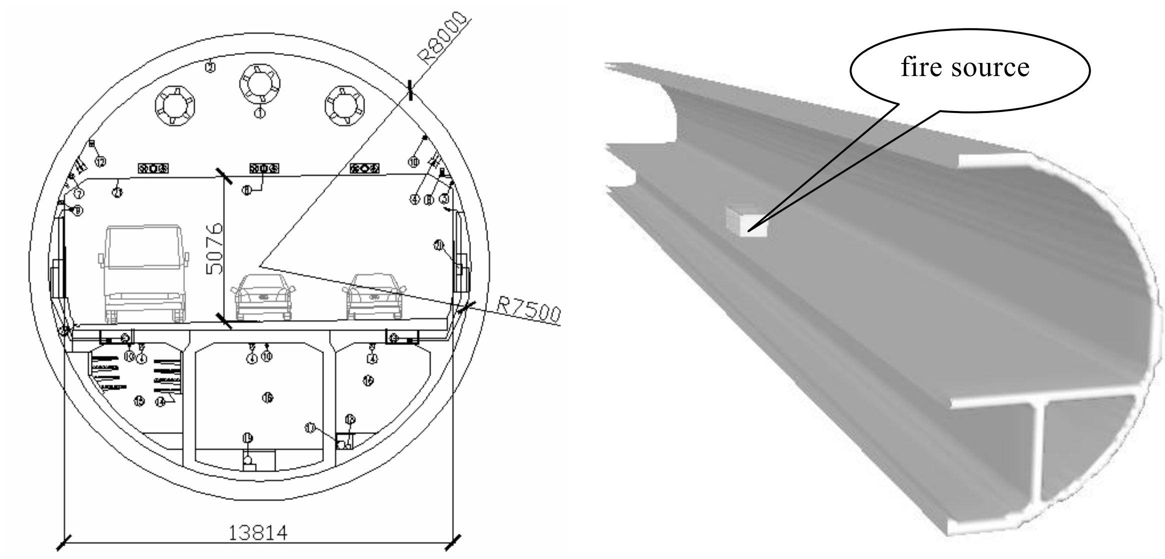
In these simulations, FDS (Fire Dynamics Simulator) 4.06 which was released by NIST(National Institute of Standards and Technology, USA) was used. FDS is a Computational Fluid Dynamics (CFD) model with LES(Large Eddy Simulation)of fire-driven fluid flow. The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Thermal radiation is computed using a finite volume technique on the same grid as the flow solver.

2.2 Simulation Scenario of Tunnel Fire

In this paper, the simulation length of the large cross-section road tunnel with diameter of 15m was 100m. The fire source was located at 37m from the upstream ventilation cross-section and 63m from the downstream ventilation cross-section, as shown in Fig.1.

The Heat Release Rate(HRR) of fire source was based on the EUREKA project conclusion, which were completed by nine Europe countries in abandon tunnel. The HRR curve was shown in Fig.2[1], a lorry was supposed to be burned in the tunnel. The fire scenarios included: (1) scenario 1: none ventilation; (2) scenario 2: longitudinal ventilation, the velocity set as 2m/s; (3) scenario

3: longitudinal ventilation, the velocity set as 3m/s; (4) scenario 4: longitudinal ventilation, the velocity set as 4m/s.



(a) cross-section of the tunnel (mm) (b) CFD simulation model

Fig.1 Sketch map of the tunnel fire simulation

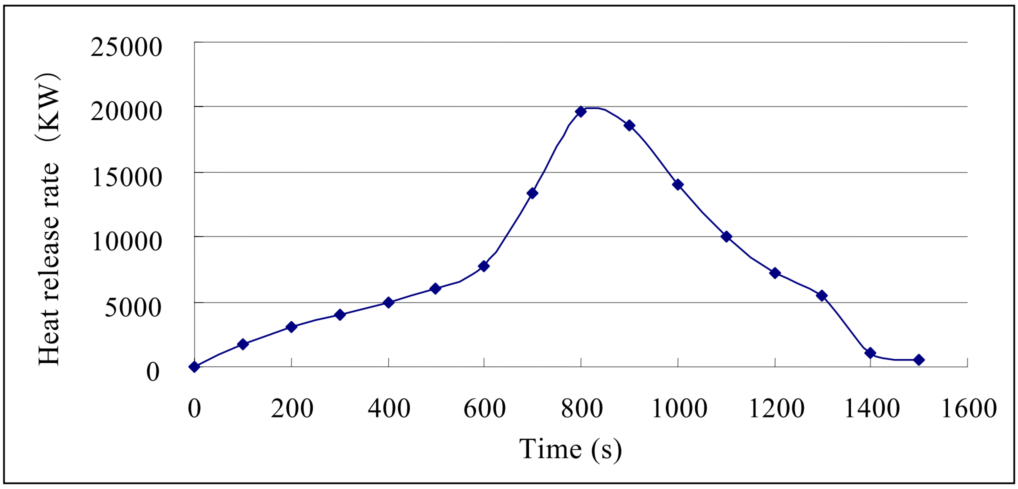
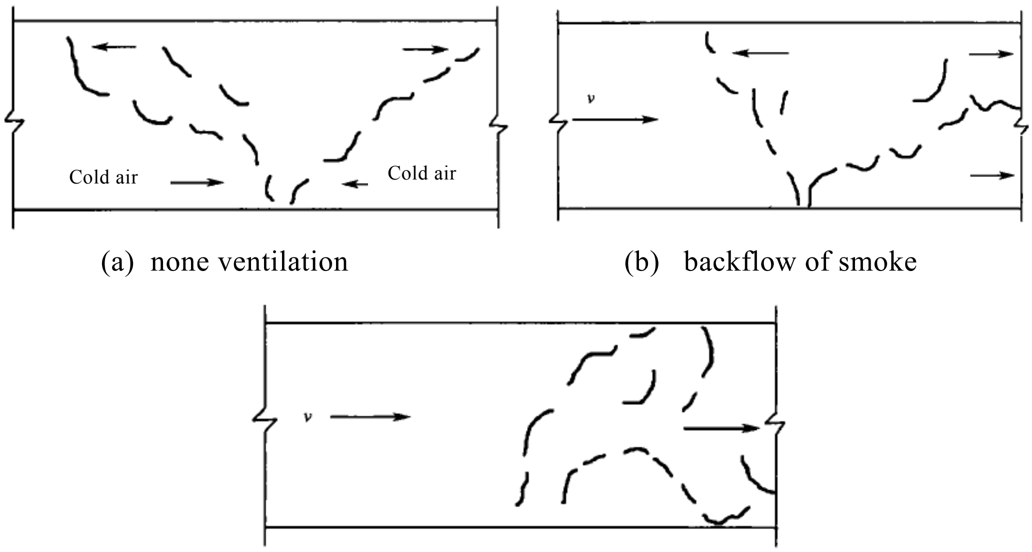


Fig.2 Heat Release Rate curve of fire scenario

3 RESULTS OF CFD SIMULATION

3.1 The Influence of Ventilation Velocity on Smoke Distribution Upstream the Fire Source

Among the upper part of the burning area in the tunnel, the hot smoke layer gradually formed as the hot smoke curled upwards. With continuous yielding of smoke from the fire source, the hot smoke layer swelled rapidly and spread towards both sides of the tunnel. Meanwhile, the cold air from the lower part of the tunnel flew to the fire source. In this way, the symmetry recirculated air was formed on both sides of the fire field, as shown in Fig.3(a). When the longitudinal ventilation was started, the smoke on both sides of the fire source emerged asymmetry. If the longitudinal ventilation velocity was quite lower and could not prevent the smoke diffusing to both sides of the fire source, the smoke would flew against the direction of longitudinal ventilation, i.e. the backflow of the smoke, as shown in Fig.3(b). This was unfavourable for prevention of fire smoke spreading and safety of firemen. Hence, in order to prevent the backflow of the smoke, the longitudinal ventilation velocity should be greater than the critical ventilation velocity, as shown in Fig.3(c).

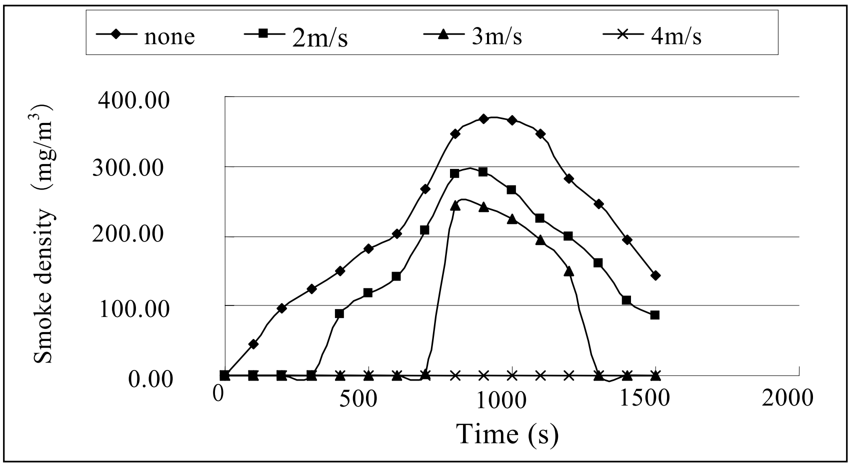


(a) none ventilation (b) backflow of smoke

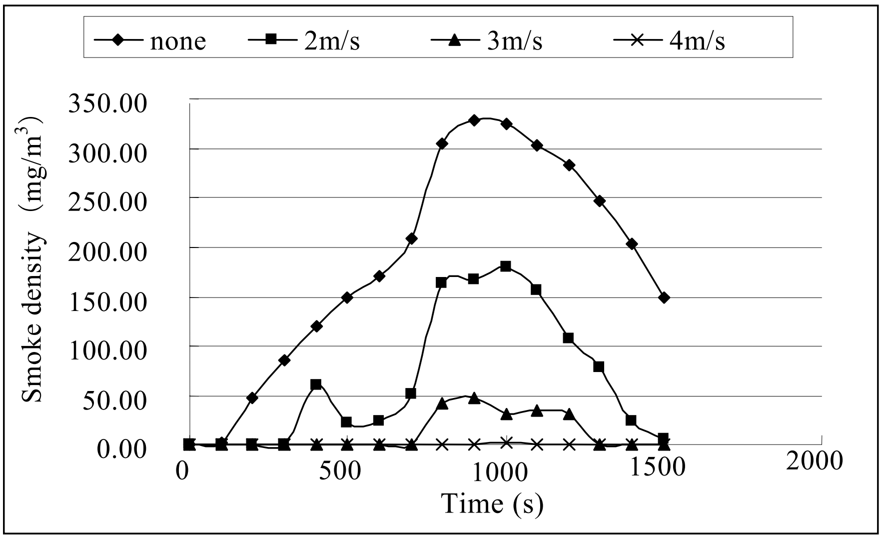
(c) flow of smoke while longitudinal ventilation velocity greater than critical velocity

Fig.3 Flow of smoke under the condition of longitudinal ventilation in tunnel fire

As presented in Fig.4, the longitudinal ventilation velocity set as 0m/s, 2m/s and 3m/s respectively, the smoke density approached to a certain value at the location of 10m upstream the fire source. As the longitudinal ventilation velocity set as 4 m/s, the corresponding smoke density achieved almost zero. The simulation results illustrated that the flow back of smoke emerged while the longitudinal ventilation velocity set as 3m/s. If the relevant velocity set as 4m/s, the smoke did not flow towards the direction upstream the fire source. It indicated that the critical ventilation velocity approximated 4m/s.



(a) at the position of vault

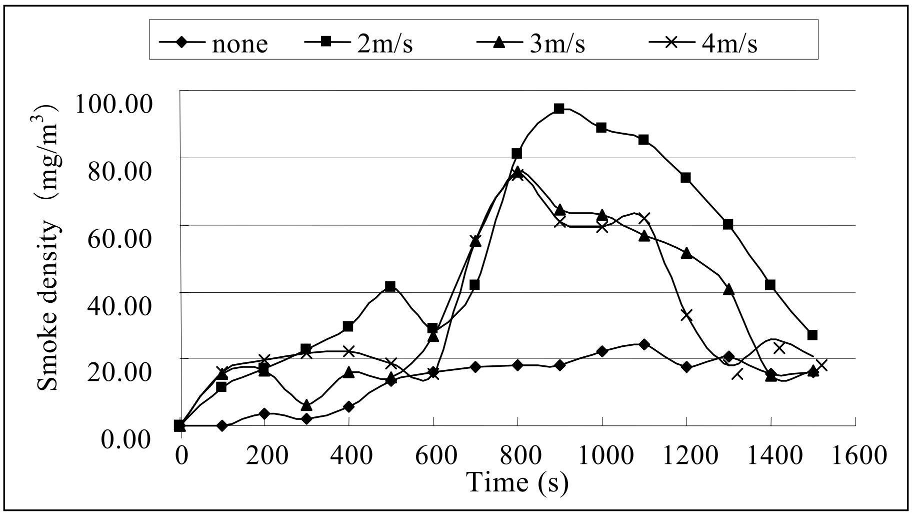


(b) at the position of 6.4m height

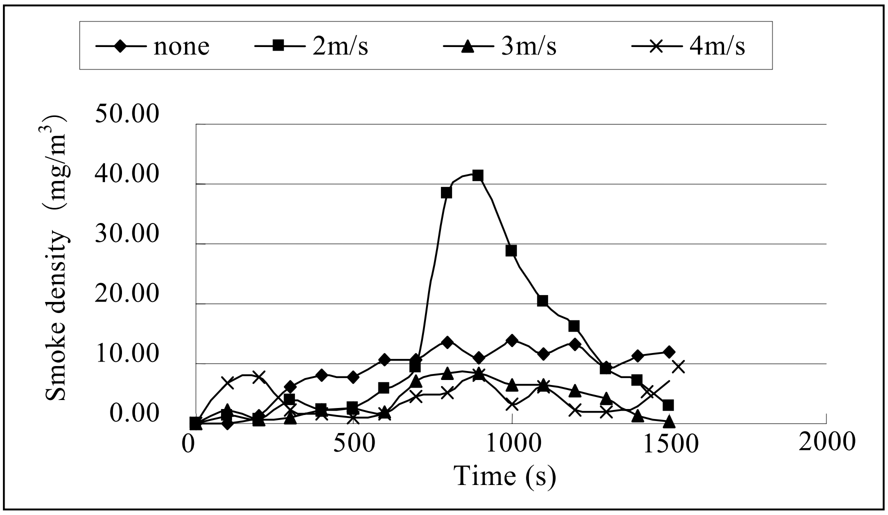
Fig.4 Simulation results of smoke density at the location of 10m upstream the fire source

3.2 The Influence of Ventilation Velocity on Smoke Distribution Downstream the Fire Source

Among the area downstream the fire source, the longitudinal ventilation accelerated the spreading velocity of smoke. However, the longitudinal ventilation also scattered the diffusion scope of smoke and decreased the smoke density, as shown in Fig.5. At the beginning stage of the tunnel fire, the smoke density increased as the longitudinal ventilation enhanced the propagation velocity of smoke. But along with the development of the fire, the smoke was gradually dispersed by the ventilation. The increase of ventilation velocity decreased the smoke density. Hence, the smoke density would not be simply proportional to the change of longitudinal ventilation velocity. If the longitudinal ventilation velocity was too large, the smoke was easily dispersed and the smoke density would be decreased. If the longitudinal ventilation velocity was too small, the smoke would spread quite slowly. While the HRR approached its peak value at the simulation time of about 900s, the smoke density achieved maximum value when the longitudinal ventilation velocity set as 2m/s.



(a) at the position of 4.9m height

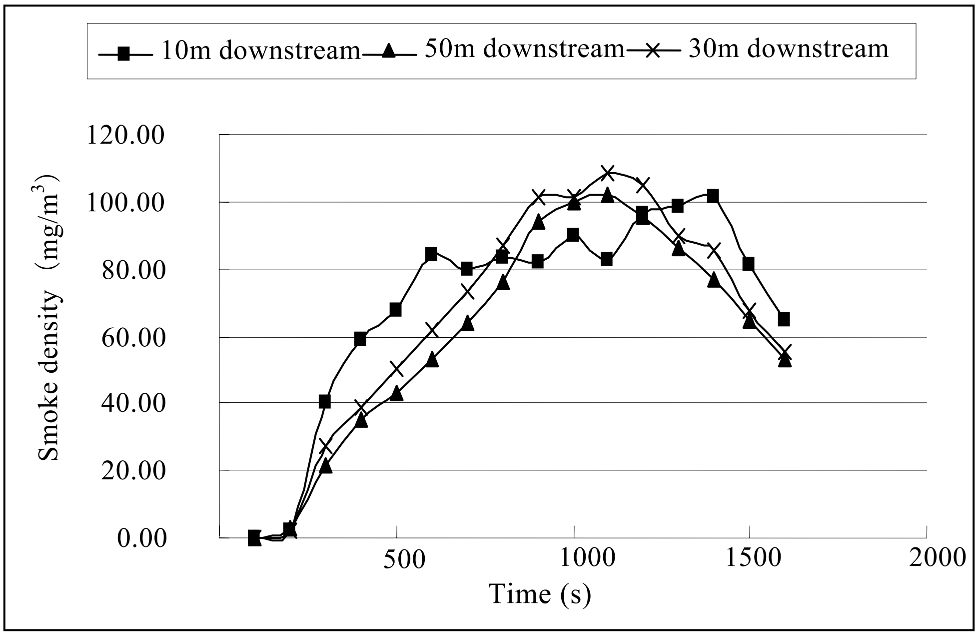


(b) at the position of 2.1m height

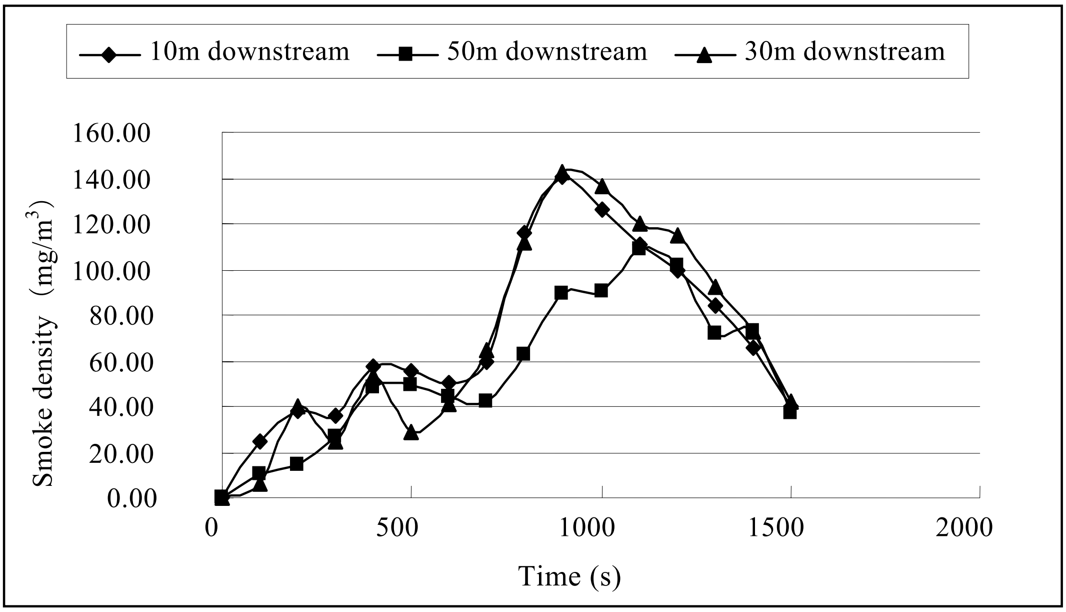
Fig.5 Simulation results of smoke density at the location of 10m downstream the fire source

3.3 The Influence of Ventilation Velocity on Smoke Longitudinal Distribution

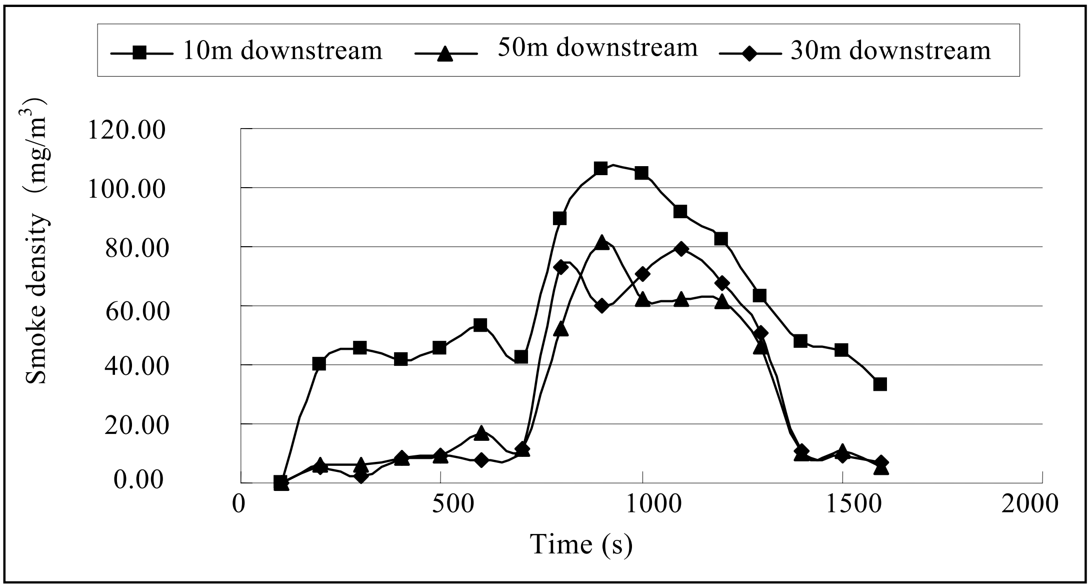
As shown in Fig.6, while the longitudinal ventilation velocity was quite large, the smoke density near the fire source got comparatively large. The maximum smoke density value emerged quite earlier. If the longitudinal ventilation velocity was quite small, the smoke density far from the fire source got comparatively large and emerged quite later. The smoke density achieved maximum value when the longitudinal ventilation velocity set as 2m/s. It was evident that the longitudinal ventilation could disperse the smoke and enhanced the propagation of smoke. However, the smoke could accumulate at a certain location and result in a quite large density if the ventilation velocity was not large enough.



(a) none ventilation



(b) longitudinal ventilation velocity set as 2m/s

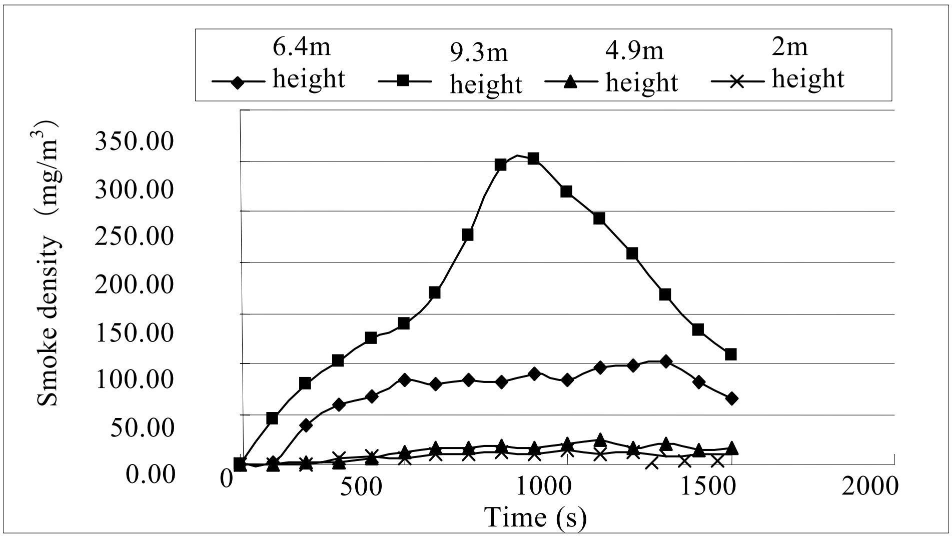


(c) longitudinal ventilation velocity set as 4m/s

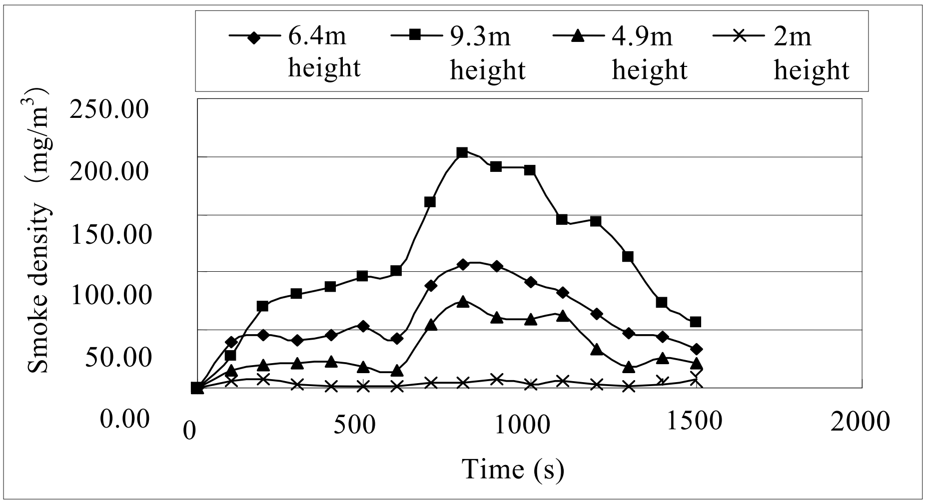
Fig.6 Longitudinal distribution of smoke density

3.4 The Smoke Density Distribution of Cross-section

Based on the buoyancy of the hot smoke, the smoke rose rapidly and spread towards both sides of the fire source. When the smoke approached the vault, it began to descend towards the road surface. As for a certain cross-section, the smoke density decreased from the top to the bottom and achieved the maximum value at the vault and caused the highest temperature. Therefore, the fire protection of the tunnel vault should be strengthened and the corresponding fire protection facility should be installed in the tunnel.



(a) none ventilation



(b) the longitudinal ventilation velocity set as 4m/s

Fig.7 Simulation results of smoke density for cross-section at the location of 10m downstream the fire source

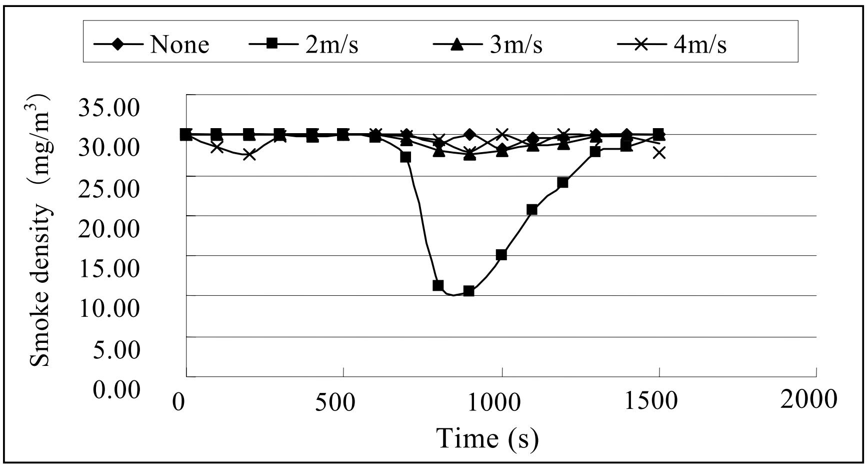


Fig.8 Simulation results 2.1m height visibility at the location of 10m downstream the fire source

4 CONCLUSIONS

(1) The tunnel ventilation system should be utilized to prevent the fire smoke spreading upstream and avoid the backflow of the smoke. Hence, it would provide a favourable environment for evacuation, fire-fighting and rescue. As for a certain large cross-section road tunnel, the critical ventilation velocity should be further confirmed.

(2) The longitudinal ventilation velocity should not be too small during the tunnel fire. Otherwise, it would not be helpful to effectively exhaust the smoke. On the contrary, it would result in stacking of smoke which was harmful to evacuation. The worst scenario emerged while the longitudinal ventilation velocity set as 2m/s, as shown in Fig.8.

(3) The longitudinal distribution feature of the smoke in tunnel fire related closely with ventilation velocity. The longitudinal ventilation could effectively decrease the smoke density among the area far from the fire source.

(4) As for the transverse distribution feature of the smoke in tunnel fire, the smoke density achieved the maximum value at the tunnel vault. It would decrease from the top to the bottom of the tunnel cross-section.

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